Making of the Atomic Bomb

The Science and History

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Motivation for Manhattan Project

- Nazis took control of Germany in 1930s
- Persecuted Jewish German scientists fled Germany
- German scientists split uranium atom in 1938
- Neils Bohr revealed to world splitting of uranium atom having very large energy release ($E = mc^2$) in 1939
- Germany invaded Poland in late 1939 (beginning of WW II)
- Hungarian physicists Leo Szilard and Eugene Wigner concerned that Germany would develop super weapon they called atomic bomb
- Germany invaded France and Norway in 1940, gaining access to resources necessary for investigating uranium fission

Pearl Harbor Attack

U.S. supplying war materials to England via Lend-Lease program, but did not plan to declare war on Axis powers (Germany, Italy, Japan) ….

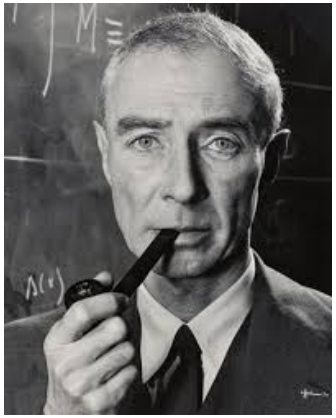
until the “date which will live in infamy” happened.

Congress declared war on December 8, 1941, and everything changed ….

Forever.

The Manhattan Project

- Leo Szilard convinced Albert Einstein to sign letter to President Roosevelt, alerting him to importance of developing atomic bomb in case Hitler pursued development of such a bomb
- Roosevelt established Advisory Committee on Uranium in 1939; authorized Enrico Fermi to investigate uranium fission chain reaction
- Manhattan Engineer District (what became Manhattan Project) established under U.S. Army Corps of Engineers in June 1942

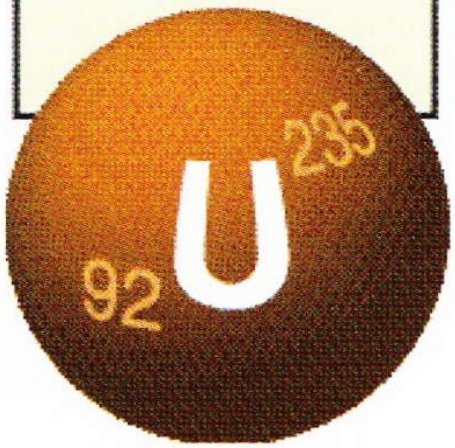


- Colonel Leslie Groves promoted to Brigadier General and appointed to direct Manhattan Project in September 1942
- Groves chose Dr. J. Robert Oppenheimer to create laboratory where atomic bomb could be developed

Location of Major Manhattan Project Sites

Manhattan Project Programs

Oak Ridge
(Enriched Uranium)

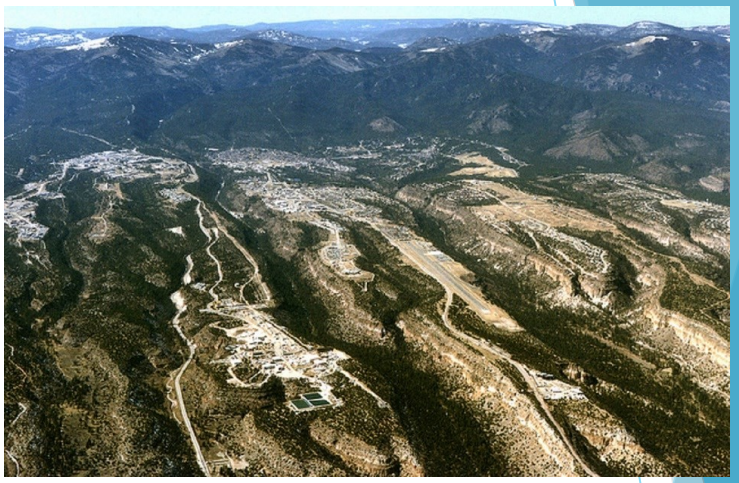


Los Alamos
(Design and Production)

Hanford
(Plutonium)

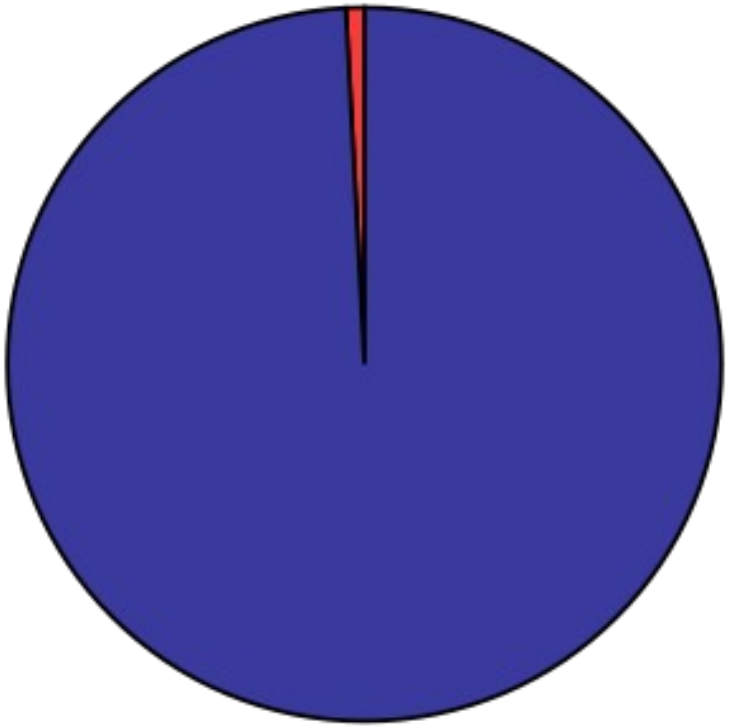
Los Alamos – Where the Bombs Were Designed

Establishing Los Alamos



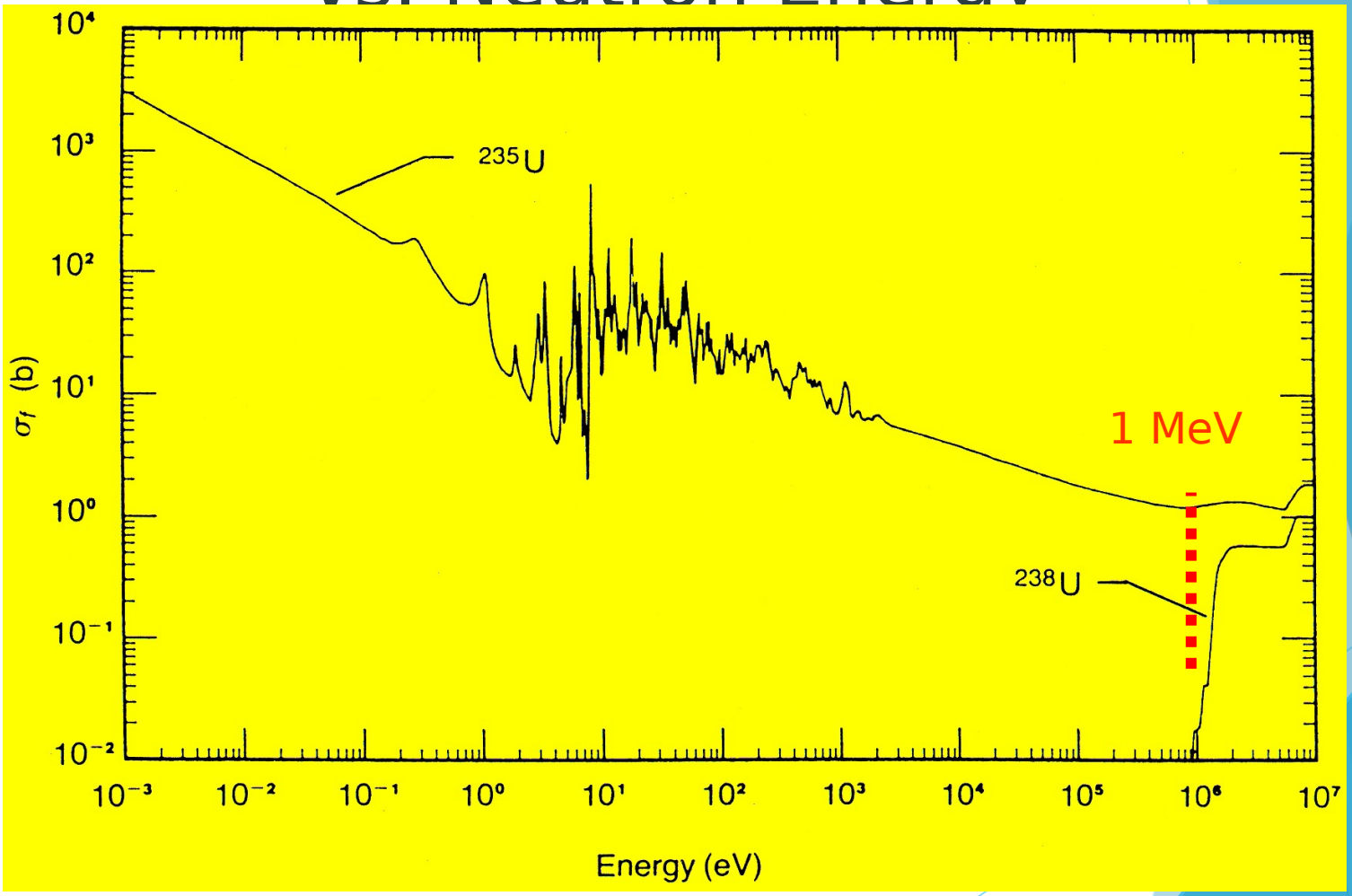
- Oppenheimer familiar with Los Alamos Ranch School located on remote mesa in New Mexico; good site for developing atomic bomb due to remote location and suitability for military security
- Government purchased school in 1942
- Labs, housing and hospital built; scientists, engineers, and technicians hired; families arrive, atomic bomb research begins in earnest

Natural Uranium Composition



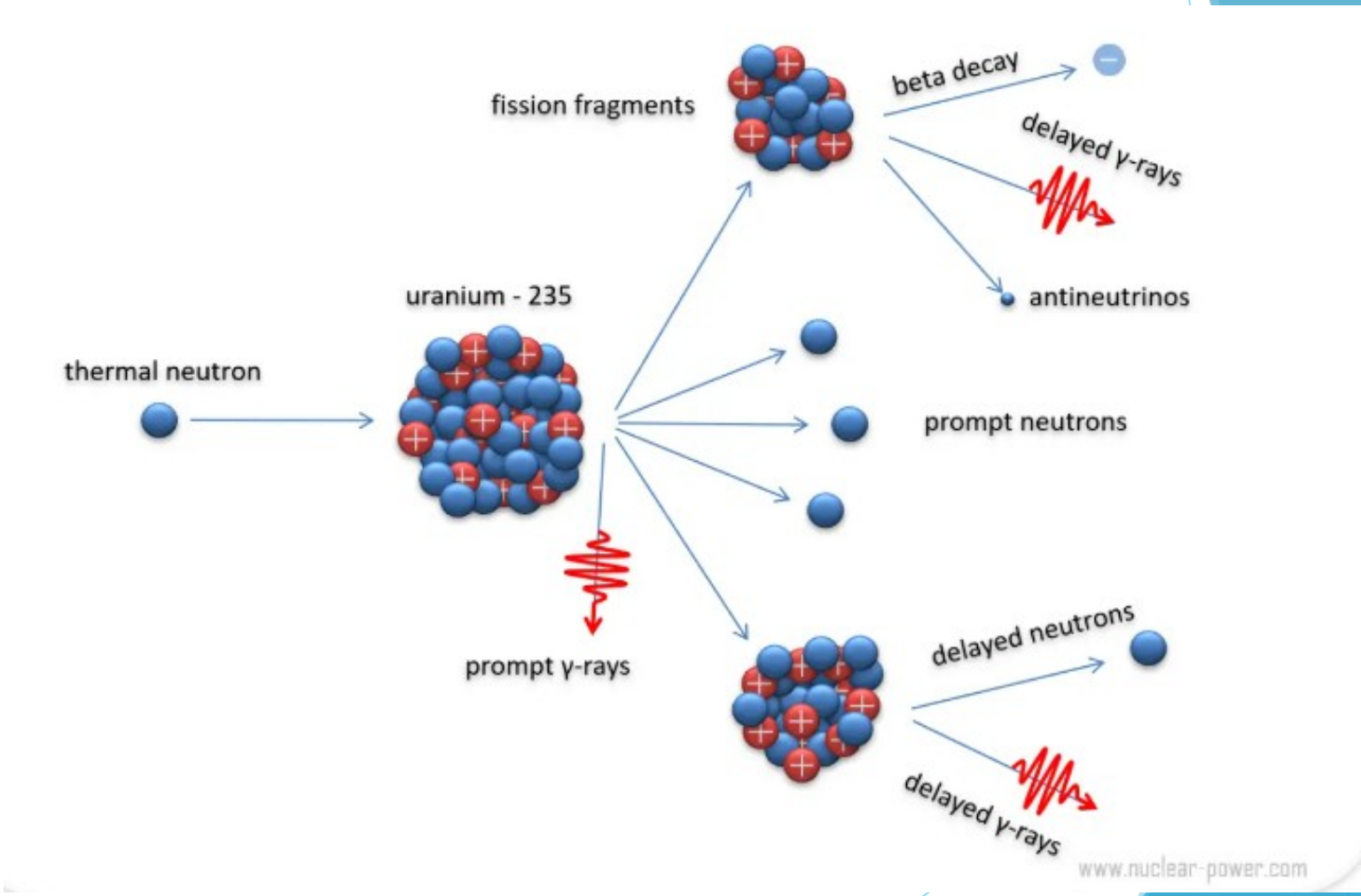
Natural uranium (NU)
>99.2% U-238
≤0.72% U-235

U-235 and U-238 Fission Cross-Sections vs. Neutron Energy

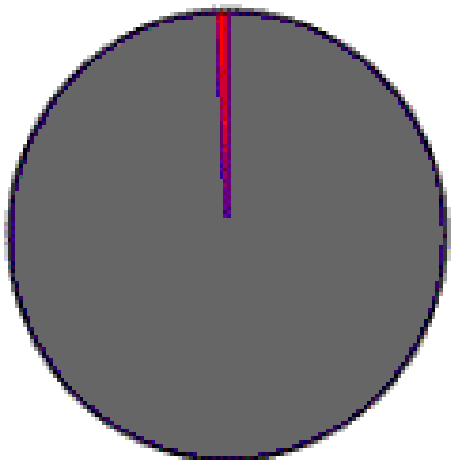


Fission cross section (σ_f) expressed in barns (b), where a barn is 10^{-24} cm^2

U-235 Fission

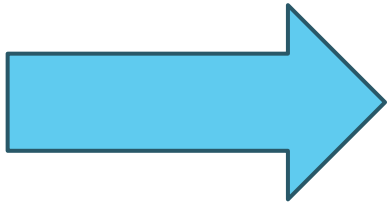


Weaponizing Uranium



Naturally occurring Uranium

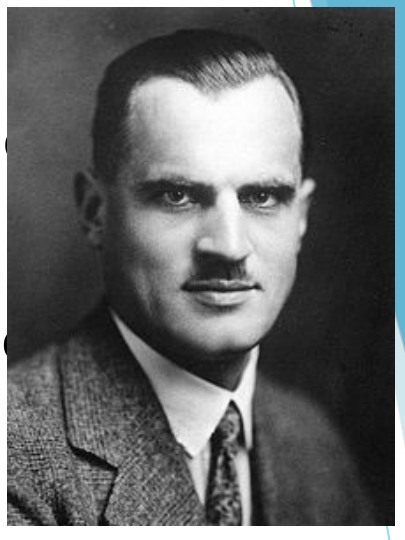
99.2742 % U-238
0.7204 % U-235



Weapons Grade Uramium
90% U-235
10% U-238

The Uranium Project

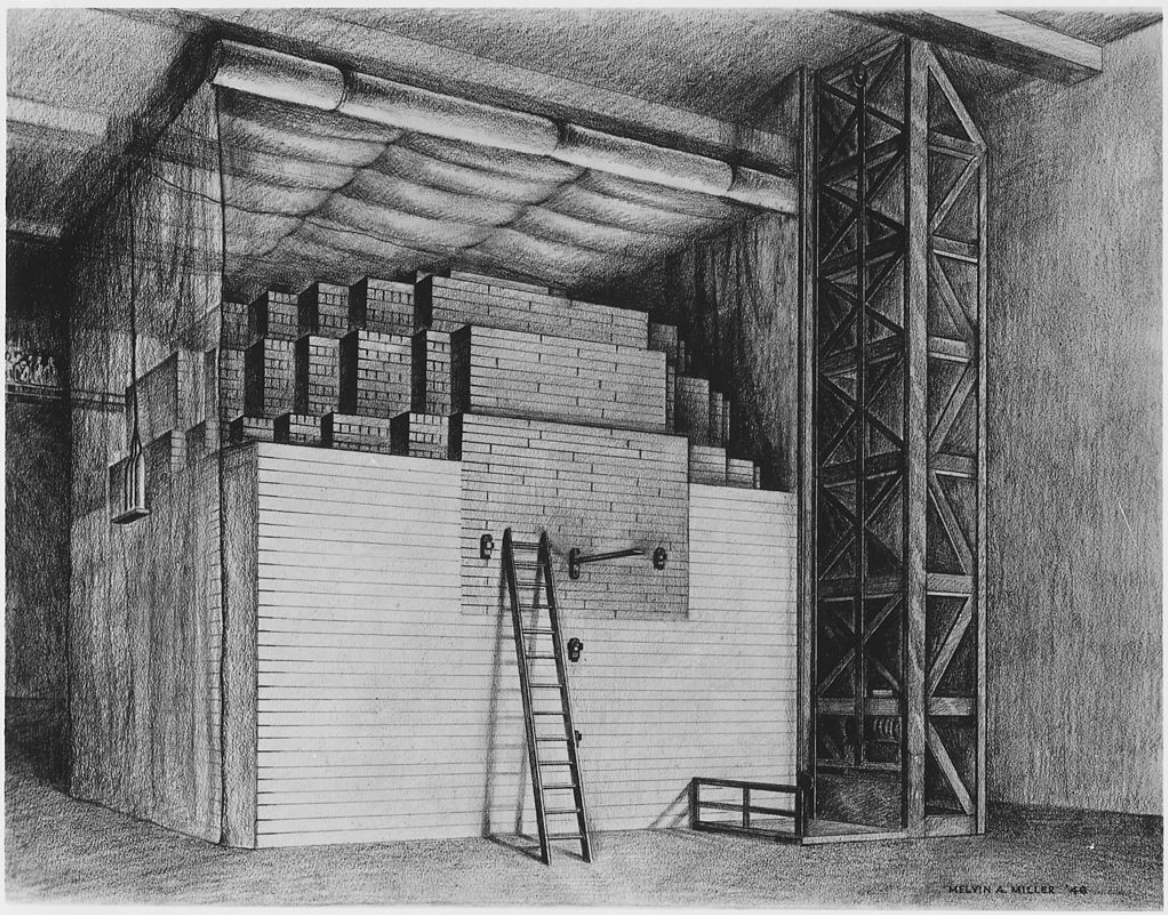
- Uranium procured from Africa
- In April 1941, Arthur Compton appointe
  head of committee to report on
  uranium program
- May 1941 report foresaw development
  nuclear weapons using uranium-235



- Enrico Fermi headed group that built
  natural uranium, graphite-moderated
  test reactor at University of Chicago
- Uranium separation factory built in
  eastern Tennessee to enrich natural
  uranium in U-235 isotope

University of Chicago Met Lab – Where Self-sustaining Fission Chain Reaction Achieved

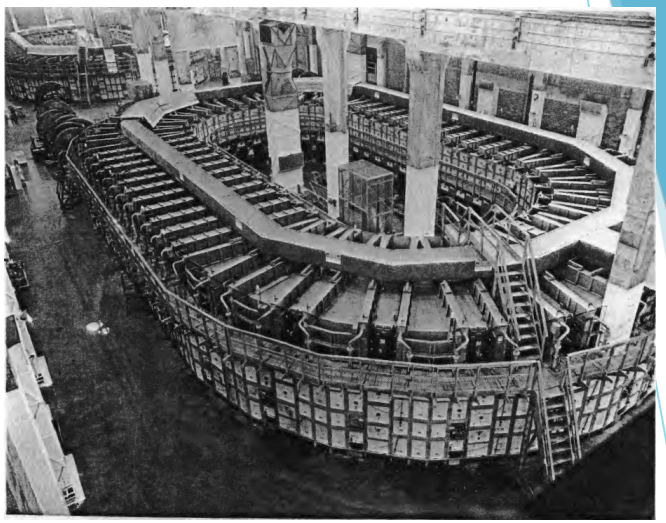
Chicago Pile 1



Construction of CP-1 began in November 1942 and achieved nuclear criticality on December 2, 1942

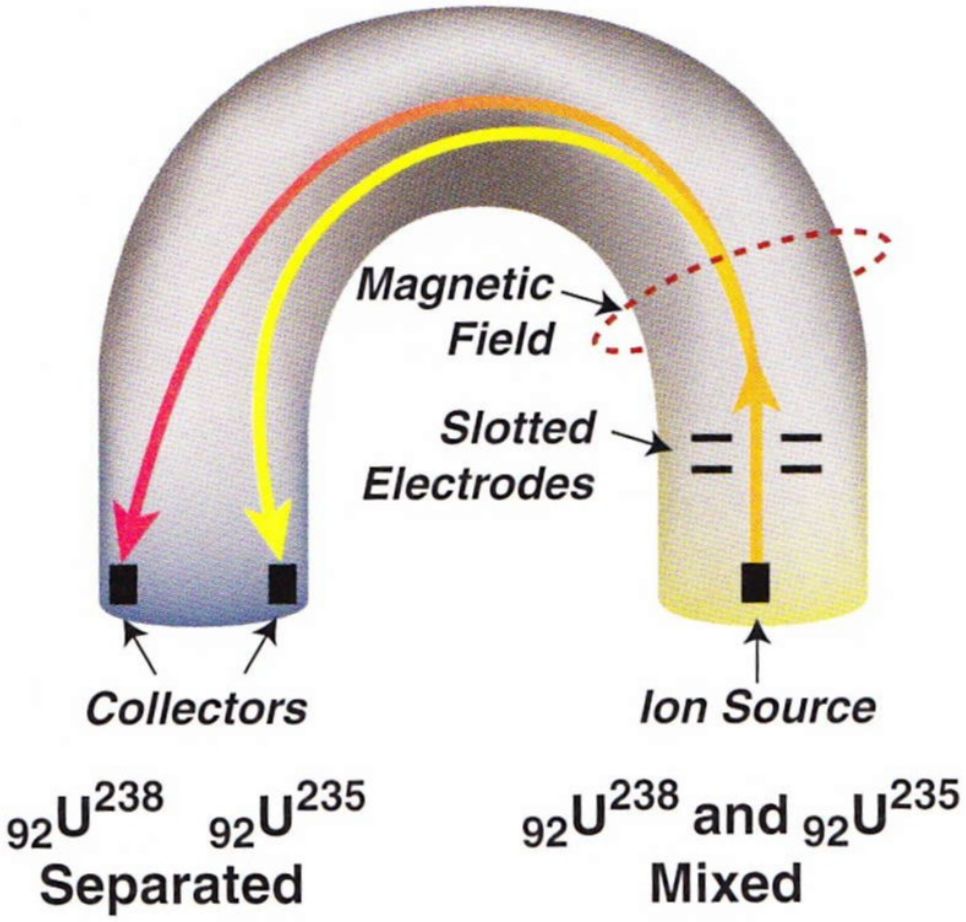
Oak Ridge – Where Uranium was Enriched

Y-12 Electromagnetic Separation Plant



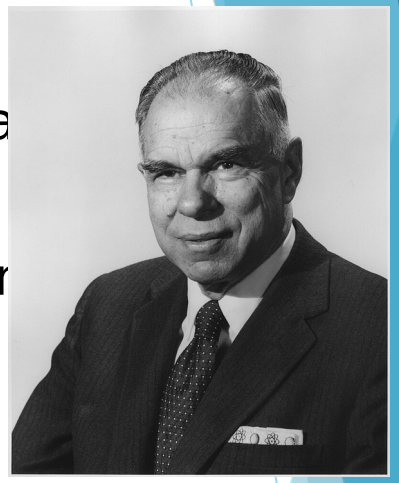
Construction of Oak Ridge Y-12 facility for electromagnetic separation of uranium isotopes (enrichment of natural uranium) began in February 1943; operation began in November 1943

Uranium Enrichment by Electromagnetic Separation

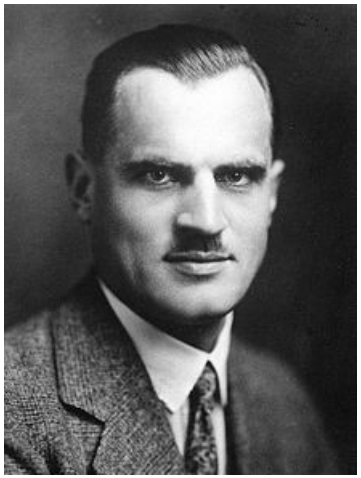


Hanford – Where Plutonium was Produced

The Plutonium Project

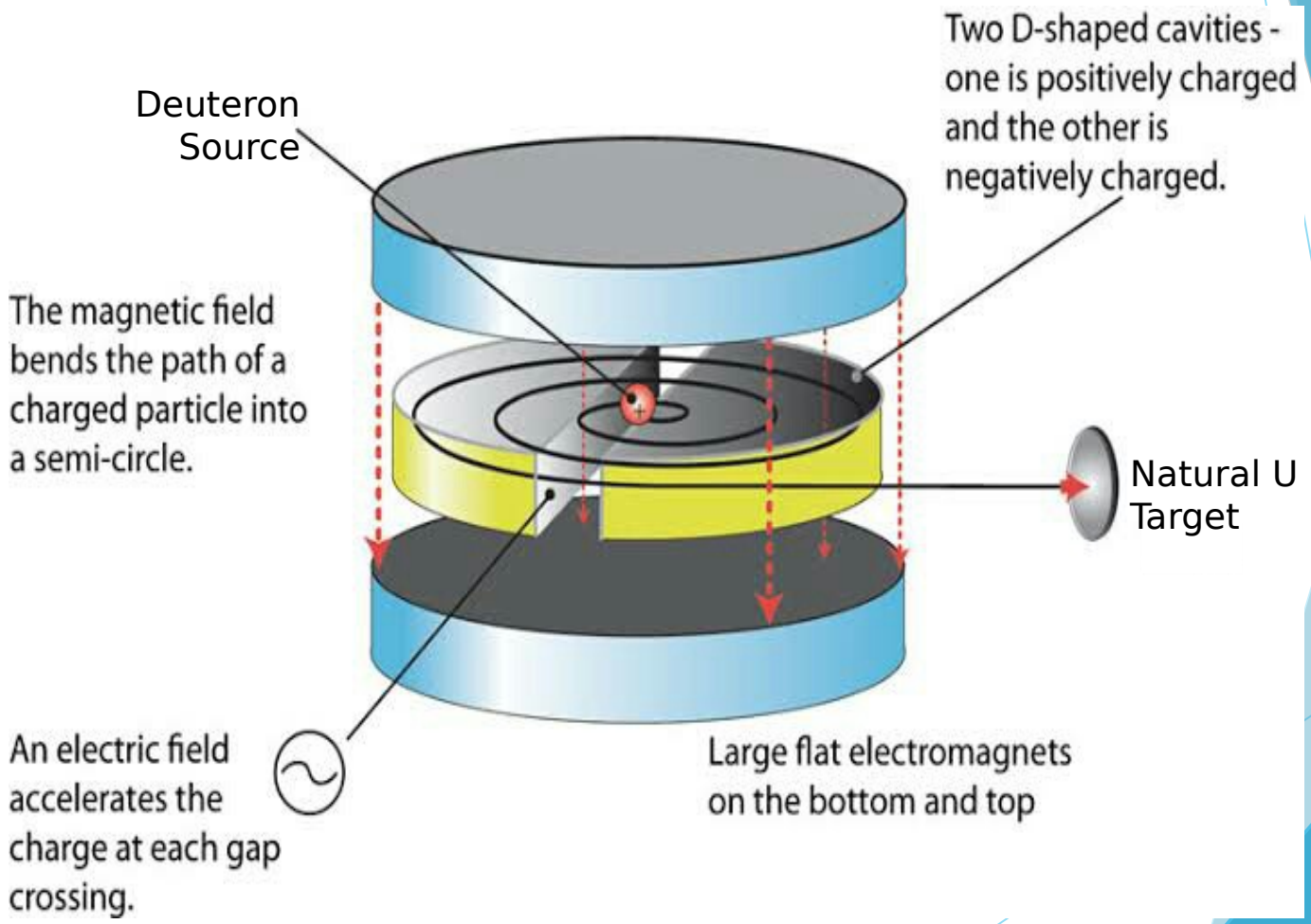


- In late 1940, Dr. Glenn Seaborg created first plutonium in cyclotron by bombarding natura uranium with deuterons
- Arthur Compton placed in charge of plutoniu project in December 1941

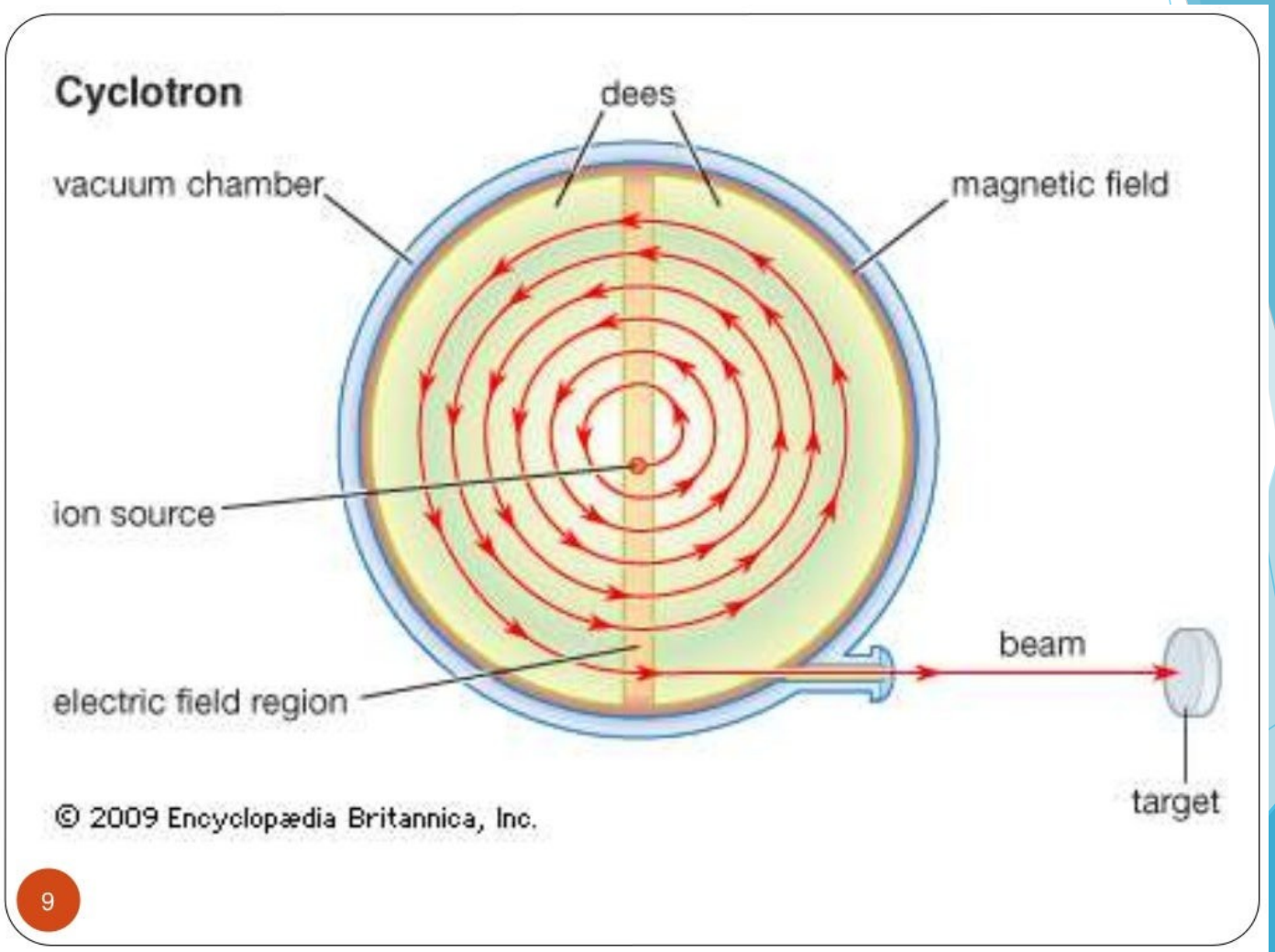


- Construction of plutonium production reactors at Hanford, WA began in August 1943
- Successful production of Pu-239 from U-238 neutron capture demonstrated at X-10 reactor at Oak Ridge in February 1944
- Hanford B Reactor began producing plutonium in November 1944

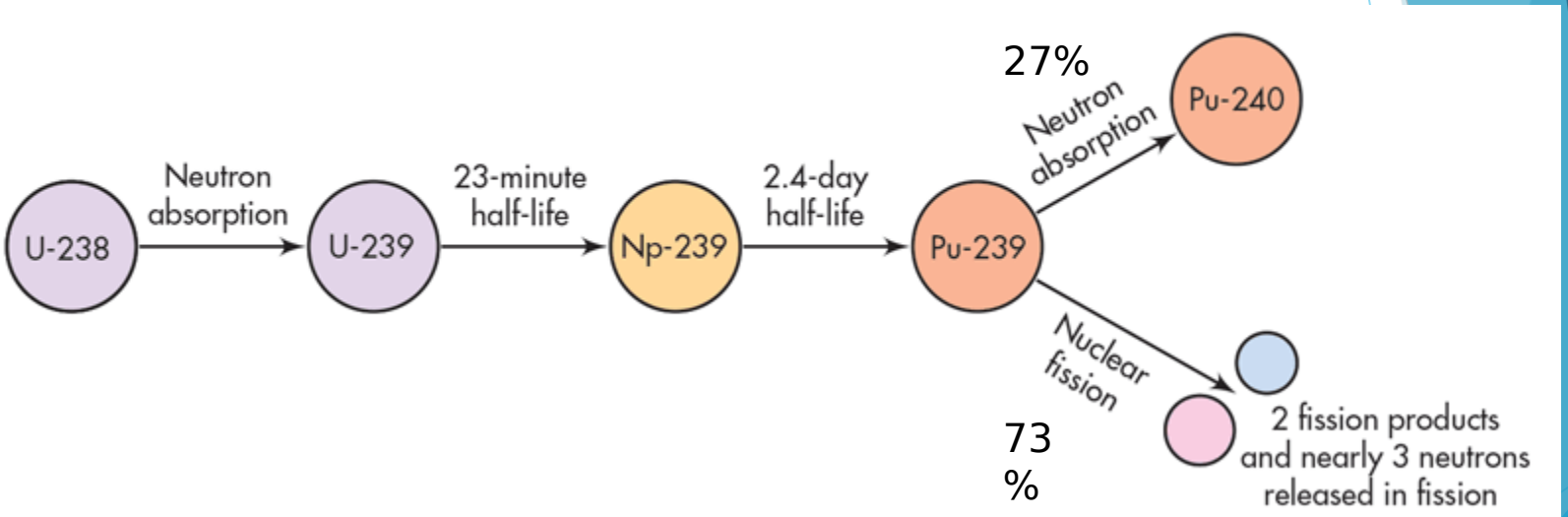
Discovery of Plutonium by Deuteron Bombardment of Uranium in Cyclotron


Deuteron Source
Two D-shaped cavities - one is positively charged and the other is negatively charged.
The magnetic field bends the path of a charged particle into a semi-circle.
Natural U Target
An electric field accelerates the charge at each gap crossing.
Large flat electromagnets on the bottom and top

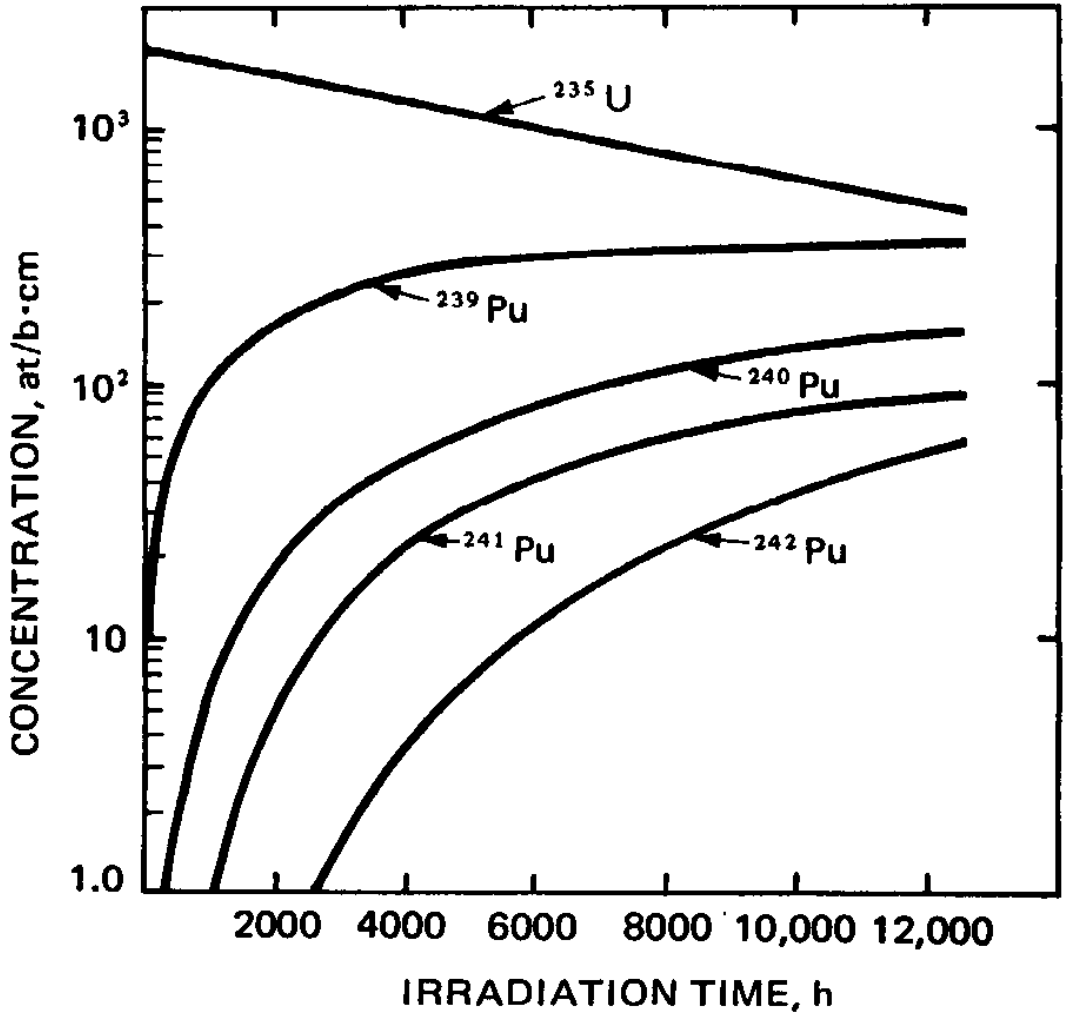
Discovery of Plutonium (cont.)



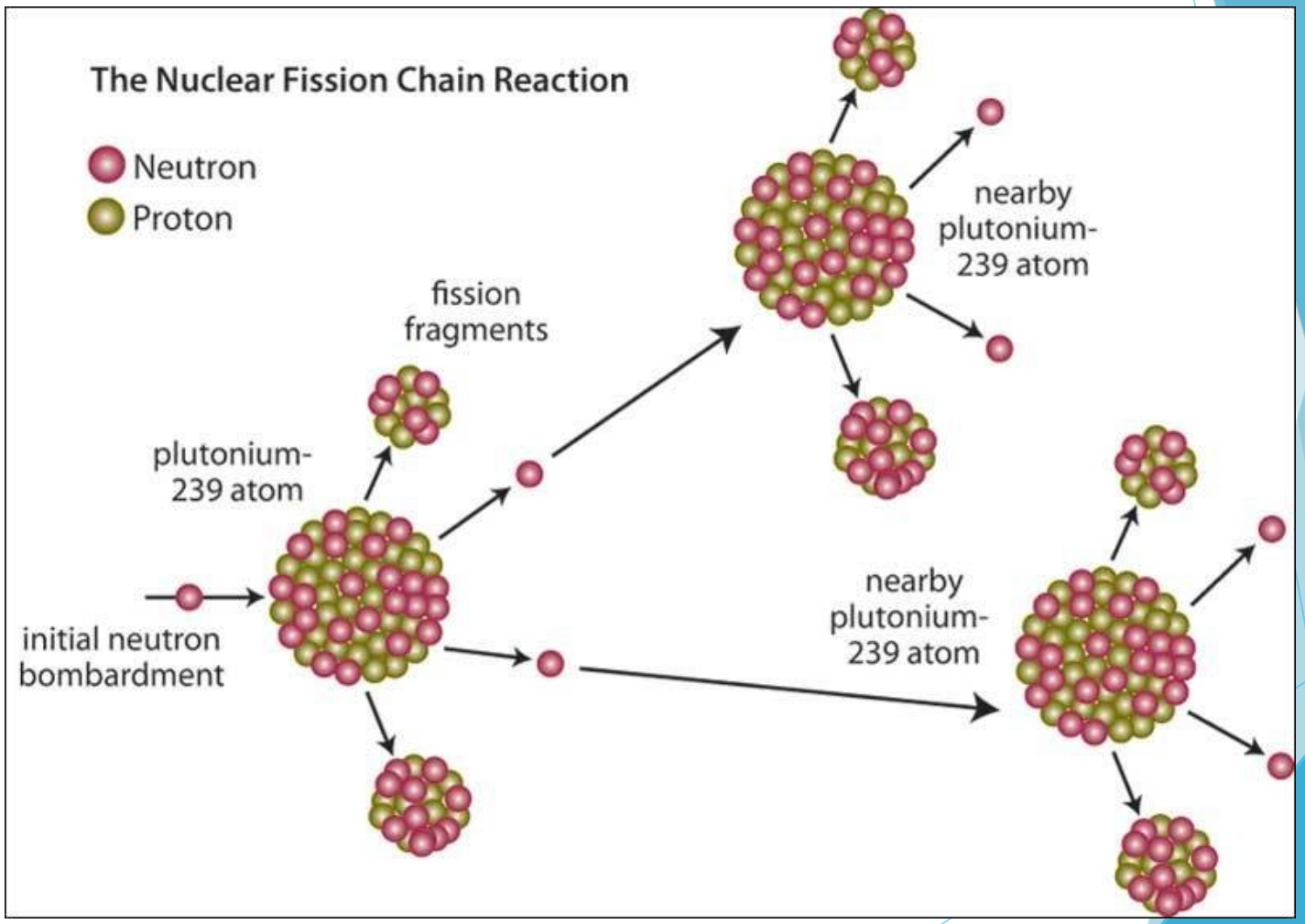
Plutonium Production from U-238



Pu Isotope Buildup with Irradiation Time



Pu-239 Fission



Hanford B Reactor

Hanford B reactor, world's first full-scale nuclear
reactor, went into service on September 26, 1944

Hanford T Plant

Construction of T Plant for extracting plutonium from uranium fuel rods irradiated at the B Reactor completed in 1944

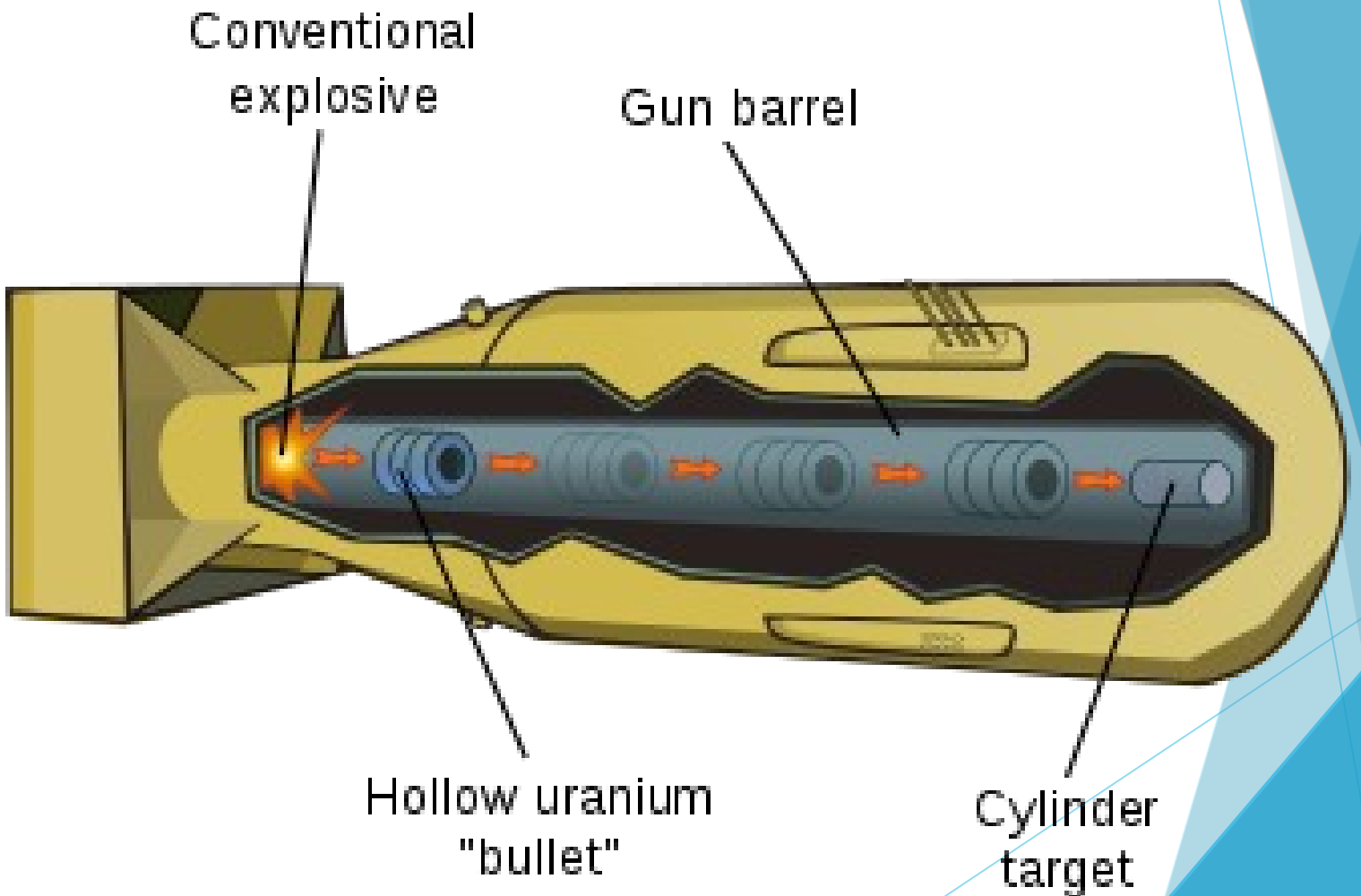
The Atomic Bombs

Fission Device Physics

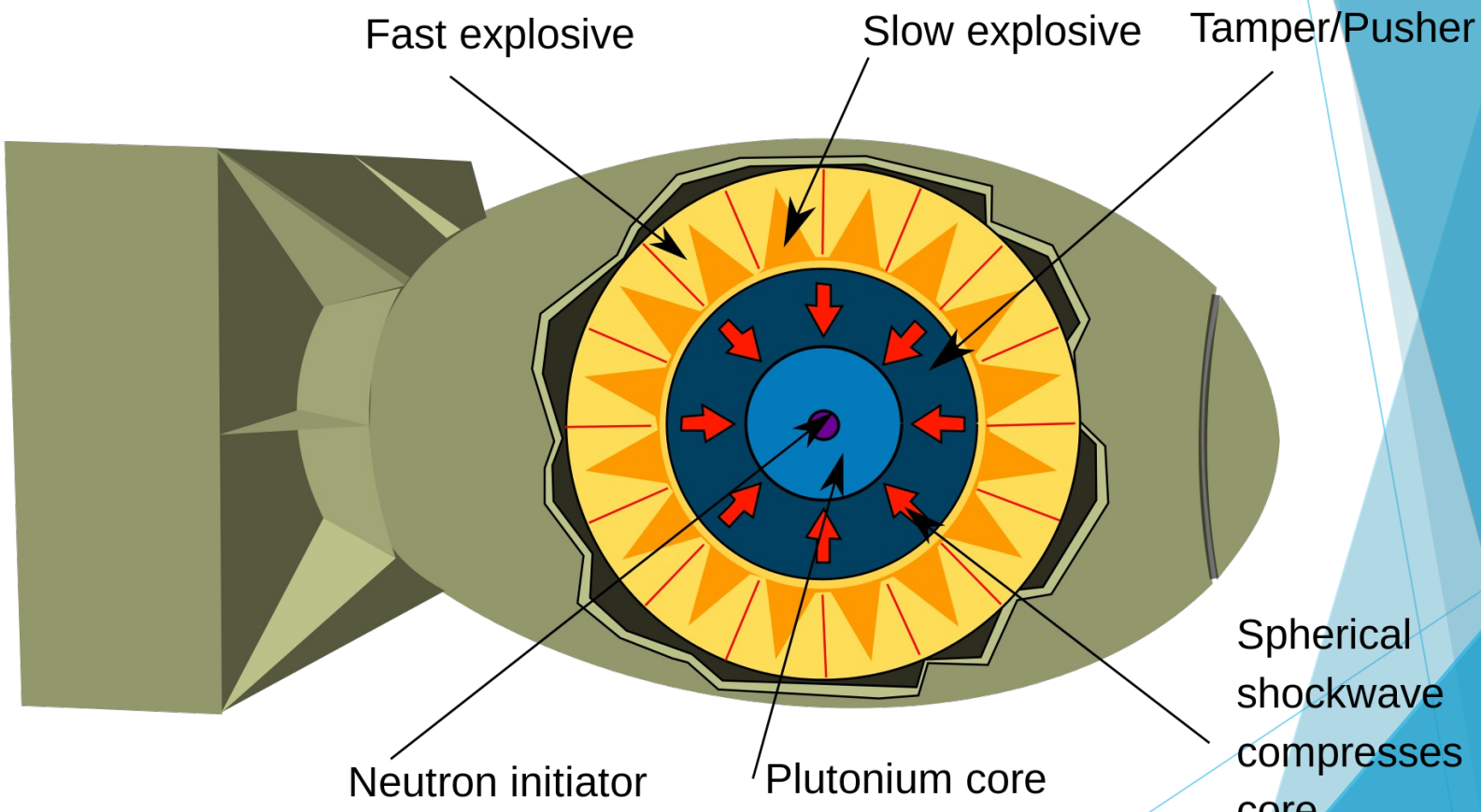
- Two ways to assemble a super-critical mass in a weapon:
  - Gun assembly – slamming two masses together
  - Implosion – compressing hollow sphere into solid ball
- Little Boy – code name given to uranium atomic bomb
  - Gun-assembly device
  - Simple design requiring only one detonator

- Fat Man – code name given to plutonium atomic bomb
  - Implosion-assembly device (spontaneous fission of Pu-240 causing premature fission of Pu-239 negated gun-assembly)
  - Complex design requiring 32 detonators

Gun-Type Assembly Device



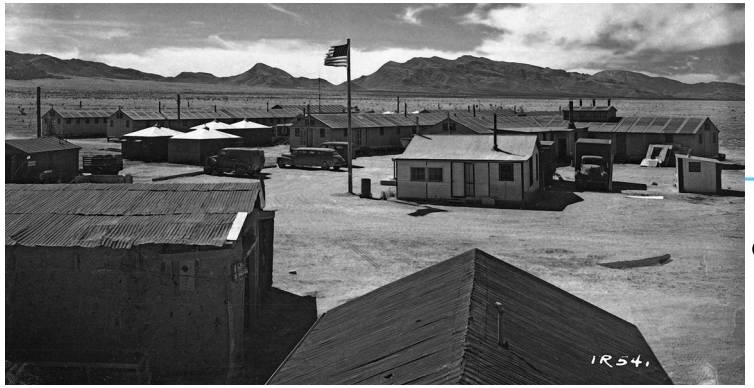
Implosion-Type Device



Trinity – Where the Plutonium Bomb was Tested

Trinity Test of Plutonium Bomb

- Test planned for barren area north of White Sands Artillery Range
  - McDonald Ranch procured by eminent domain – where Gadget test device was assembled



  - Built base camp housing, several miles of roads, earth and concrete bunkers, 100-foot-tall test tower
  - Positioned hundreds of gauges and instruments, radar and searchlight installations, more than 50 cameras, and 500 miles of wires

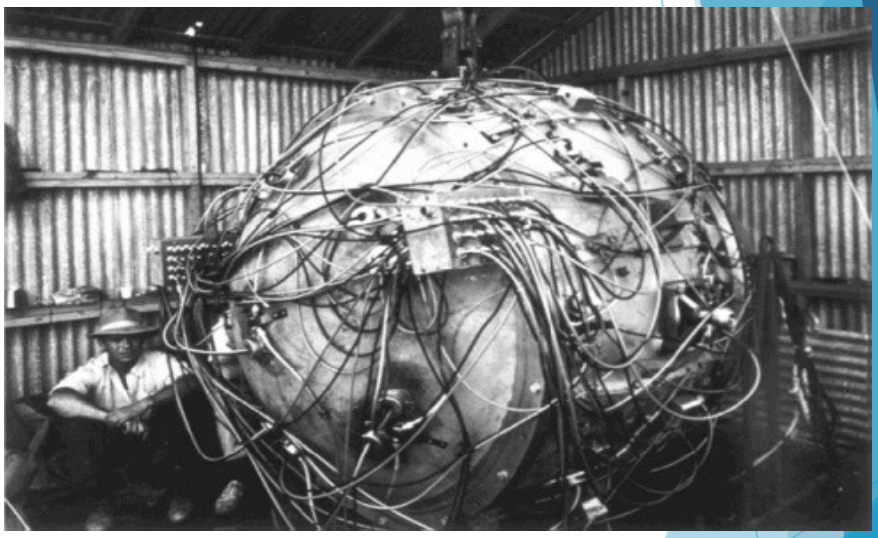
Trinity Test (cont.)

- Test site construction began November 194 and completed in June 1945
- Scientists and military officers observed test from base camp ten miles from ground zero

- Two days before scheduled test on July 16, 1945 scientists became convinced simultaneous initiation of all 32 detonators would occur

Trinity Test (cont.)

Test Tower



Gadget device

Trinity Test (cont.)

Near dawn on July 16, 1945, the world entered the Nuclear Age

Opposition to Using the Bomb

Leo Szilard Opposition

- Led scientists opposed to dropping atomic bomb on Japan
- Szilard composed long memorandum to President Roosevelt in early April 1945
  - Stated that the use of atomic bomb against Japan would start atomic arms race with Russia
  - Questioned whether avoiding arm race might be more important than short-term goal of defeating Japan

- Due to Roosevelt's death on April 12, 1945, memorandum never sent

Franck Committee

- By early 1945 many scientists, particularly at Chicago Met Lab, began questioning advisability of using atomic bomb as weapon
- One group known as Committee of Social and Political Implications (Franck Committee)
  - Included Leo Szilard and Glenn Seaborg
  - Sent petition with 64 Met Lab signatures protesting use of atomic bomb to Secretary of War Stimson in June 1945

Manhattan Project Opinion Poll

- Concurrent with Franck Committee petition, Arthur Compton compiled results of opinion poll surveying most of major Manhattan Project facilities
- 130 of 150 replies to questionnaire
  - favored military use of weapon only after all nonmilitary means failed to bring about surrender
  - advocated demonstration of bomb for Japanese before using it militarily

Recommendation to Use the Bomb

Interim Committee and Advisory Panel

- Top-secret Interim Committee consisted of scientific, corporate, military, and government leaders
  - Established to consider most advantageous way to demonstrate bomb's power to bring about Japan's unconditional surrender, and implications of using atomic weapon and possible effects on international politics in postwar era
  - Met 5 times between May 9 and June 1, 1945

Interim Committee/Advisory Panel (cont.)

- Advisory Panel consisting of E.O. Lawrence, Fermi, Compton, and Oppenheimer
  - Specifically tasked to consider whether demonstration of bomb for Japanese prior to dropping it on populated city was warranted
  - Recommended against bomb demonstration
    - Considered demonstration insufficiently spectacular to provide needed shock
    - Concerned that bomb might not work and failure would only bolster Japanese resolve to fight on
- June 1, 1945 Interim Committee report to President Truman contained unanimous recommendation to use bomb against Japan without prior warning

Decision to Use the Bomb

The Buck Stops Here

- President Truman's primary goal, consistent with FDR's, was to bring quick end to war with minimal loss of American lives

- Based on Japan's dogged resistance at Iwo Jima, Okinawa, and other islands, and heavy losses inflicted on American ships from Japanese kamikaze missions, Allies determined as many as 250,000 to one million Allied soldiers would die if invasion of Japan took place

The Buck Stops Here (cont.)

- Truman agreed with Interim Committee's recommendations and gave approval for use of atomic bomb against Japan before leaving for Potsdam Conference on July 17, 1945
  - Potsdam Declaration issued on July 26, 1945 demanding unconditional surrender of Japan; Japanese ignored declaration
  - Uranium bomb dropped on Hiroshima on August 6, 1945; Japanese refused to surrender
  - Plutonium bomb dropped on Nagasaki on August 9, 1945
  - Japan surrendered on August 14, 1945

Bomb Warnings

- General warnings
  - U.S. regularly dropped leaflets over Japanese cities, advising evacuation and warning of impending destruction
  - U.S. issued general warning of destruction through Potsdam Declaration issued on July 26, 1945
  - Leaflets did not mention atomic bomb due to secrecy surrounding Manhattan Project
- Specific warnings
  - After bombing of Hiroshima, leaflets dropped on Nagasaki (subject to debate) and other cities, warning of atomic bomb's power and urging evacuation

Atomic Bomb Fatalities

Fatality Causes and Numbers

- No exact information available regarding blast, burn, and nuclear radiation injuries as causes of fatalities
- Immediate fatalities from fireball and shockwave that destroyed inhabited structures
- Greater than 65% of fatalities among those surviving fireball and shockwave primarily from burns
- No more than 15% of bomb fatalities attributed to lethal radiation doses

Fatality Causes and Numbers (cont.)

- Total fatality estimates from bomb blast and associated blast injuries, burn injuries, and radiation sickness
  - Hiroshima – 140,000
  - Nagasaki – 70,000
- Unlikely that those who survived shockwave received lethal radiation dose from detonation
  - Nevertheless, many deaths that occurred in weeks, months, and years following detonation attributed to lethal radiation doses
  - Much more likely that those who remained in area after blast ingested heavy-metals (e.g., uranium and plutonium) in radioactive fallout and suffered more from consequences of heavy-metal toxicity (i.e., heavy-metal poisoning)

Fatality Causes and Numbers (cont.)

- Unfortunately, radiation issue will forever be embroiled in controversy
- For purposes of comparison, approximately 100,000 Japanese died in March 9, 1945 firebombing raid on Tokyo
  - While some still contend U.S. not justified in dropping atomic bombs on Hiroshima and Nagasaki, no similar allegation made about firebombing of Tokyo

Relative Atomic Bomb Fatality Map for Albuquerque

Supplemental Slide

Calutron operators at their panels in the Y-12 plant at Oak Ridge, Tenn.

Fissile Material Critical Mass